DTIC FILE COPY

AD-A226 335

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE: 16 July 1990

3. REPORT TYPE AND DATES COVERED: Interim Report - 8/1/89 to 7/31/90

4. TITLE AND SUBTITLE: Peripheral Limitations on Spatial Vision

5. FUNDING NUMBERS:
G - AFOSR-88-0292
PE - 61102F
PR - 2313
TA - A5

6. AUTHOR(S): David R. Williams, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES):
University of Rochester
Center for Visual Science
274 Meliora Hall, River Campus
Rochester, NY 14627

8. PERFORMING ORGANIZATION REPORT NUMBER: AFOSR-TR- 90 0877

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES):
JOHN F TANGNEY, Building 410
Air Force Office of Scientific Research/ NL
Bolling AFB, DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT:
Approved for public release; distribution unlimited.

AUG 3 0 1990

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This project employs psychophysical techniques to examine the limitations on spatial vision imposed by the first stages in the visual pathway. Many of the experiments capitalize on laser interferometry, which allows sinusoidal gratings to be formed on an observer's retina that are immune to optical blurring. The appearance of very high frequency gratings is distorted, or aliased, by the cone mosaic. Such moire patterns provide the basis for psychophysical techniques to assess the topography of the cone mosaic in the living eye. These measurements, accompanied by measurements of visual acuity clarify the relationship between cone spacing and resolution. Resolution was also measured under conditions in which only the M or L cones could detect the interference fringe. Visual acuity was little different than it was when both cone types detected the grating, showing that resolution is immune to photoreceptor loss under these circumstances. We also established an aliasing phenomenon caused by spatial sampling by M and L cones. Interferometry also allows measurements of the optical quality of the eye, and a viable experimental design has been established to estimate the off-axis optical quality of the eye.

14. SUBJECT TERMS: aliasing, cone mosaic, spatial sampling, contrast nonlinearity, frequency-doubling, distortion product, spatial vision, color vision

15. NUMBER OF PAGES: 10

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

18 JUL 1990

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

RESEARCH OBJECTIVES STATED IN ORIGINAL PROPOSAL

1. A psychophysical technique that employs interference fringes to spatially modulate only one cone type will be used to search for aliasing in the middle and long wavelength cone mosaics separately. The identification of aliases under these conditions may reveal the packing arrangement of these cone types in the human fovea.

2. When viewing interference fringes at spatial frequencies near 60 cycles/deg, some observers report the appearance of "red-green zebra stripes" that are qualitatively similar to the achromatic moire patterns previously reported at higher frequencies (110-120 cycles/deg). Experiments will distinguish between two competing hypotheses for this phenomenon: aliasing by M and L cones or nonlinear distortion.

3. The spacing between sampling elements in the short wavelength mechanism will be measured as a function of eccentricity in the living human eye.

4. Improved estimates of the resolution of the short, middle, and long wavelength cone mechanisms will be obtained with interference fringe stimuli.

5. The origin of the poor resolution for red-green equiluminant gratings will be clarified.

6. Random dot stereogratings will be used to search for aliasing by an array of disparity-sensitive units across the visual field, to determine the factors that limit spatial resolution for changes in depth.

7. A technique that uses moving random dot patterns will search for aliasing by an array of motion-sensitive units across the visual field, to determine the factors that limit the spatial resolution for changes in motion.

RESEARCH STATUS

Below I describe progress made during years 1 and 2 of the grant.

A-1

(1) Consequences of Spatial Sampling for Motion Perception
Nancy Coletta, Carlo Tiana and I have investigated a motion reversal phenomenon observed with drifting interference fringes that we have linked to cone aliasing. The experimental aspects of this work were completed under a previous grant from AFOSR. In the first year of the grant, we completed theoretical work related to the project, including implementation of a model of the phenomenon on a PIXAR image computer. During the second year we also produced a manuscript on this work which is now in press in Vision Research. A book chapter on some computational aspects of the problem is also in press.

(2) Measurement of the Effect of Chromatic Adaptation of Foveal Acuity and Aliasing

During year one, Orin Packer, Nobu Sekiguchi, Nancy Coletta, and I have used chromatic adaptation in an attempt to isolate either the M or L cone mosaic, with the goal of investigating resolution and aliasing with either cone mosaic alone. We have found, surprisingly, that the most extreme forms of chromatic adaptation we can produce do not alter estimates of visual resolution. This suggests that resolution is equal whether either the L or the M cone mosaic is operating alone, or both mosaics are operating together. We are currently preparing a manuscript on this work.

(3) Construction of a Two-Channel Chromatic Laser Interferometer

Nobu Sekiguchi and I have finished constructing a new laser interferometer in the laboratory for generating chromatic inference fringes. Such fringes will allow sinusoidal modulation in chromaticity as well as luminance while avoiding blurring by the optics of the eye. One of the goals in developing this device is to produce aliasing a single cone type (either M or L) to deduce the packing arrangement of the M and L cones in the fovea. Last year, we discovered a deviation in the specifications of the polarizing beamsplitters that are critical to the device. This produced a spurious interference fringe of about 8% contrast in the field of the instrument, and delayed full implementation of the device. We have now solved this problem and are poised to begin these experiments.

(4) The Cause of a Chromatic Moire Effect

During the first year, Nobu Sekiguchi, Orin Packer, and I discovered another kind of aliasing phenomenon in the fovea that occurs near the resolution limit. We pursued this phenomenon with some vigor because it was a candidate for aliasing by the M and L cones. Identifying such a phenomenon could allow the packing arrangement of M and L cones to be determined in the human. We now believe that this effect has another origin, and is produced by cone sampling coupled with an early nonlinearity in the visual system. During year 2, we produced a manuscript on this work which is now in press in Vision Research.

(5) Identification of Chromatic Aliasing by the M and L Cones

Perhaps the most exciting accomplishment during year two of the grant was establishing a phenomenon whose origin is almost certainly aliasing by the M and L cones. It turns out that this phenomenon has been known for more than 150 years, but has been attributed to temporal factors (Benham's top) instead of spatial aliasing. Fine achromatic gratings seen under conventional viewing conditions can appear to be covered with coarse red and green splotches, and this is just what one would expect from spatial aliasing by the M and L cones. We are preparing a manuscript to Nature on this discovery, and hope to pursue it further to see whether we can deduce the packing arrangement of M and L cones.

(6) Interpolation and Trichromatic Spatial Sampling
David Brainard, a recent arrival in my laboratory, and I have just launched an investigation of the rules the visual system uses to reconstruct spatial patterns under conditions of inadequate sampling. Specifically, we are interested in whether the fine resolution afforded by the luminance channel can improve the resolution of gratings seen only by S cones. Preliminary evidence suggests that a luminance grating added to an S cone grating that is too high to be resolved by the S cones alone can improve S cone resolution.

(7) Measurement of the Effect of Adaptation to Chromatic Fringes on Spatial Localization
During year two, Kyunghee Koh, Peter Lennie and I examined the mechanism by which observers adapt to chromatic fringes, such as those produced by chromatic aberration. One of the issues we are addressing is whether the adaptation effects are restricted to color or actually modify spatial localization as well. The evidence so far suggests that color appearance alone in modified with no effect on spatial localization.

(8) Development of a Model of Chromatic Opponency with Random Connections of Cones to Ganglion Cells Peter Lennie, Bill Haake, and I have been exploring the rules the visual system uses to create ganglion cell receptive fields. This work has resulted in a chapter in press.

(9) Measurement of the Off-axis Optical Quality of the Human Eye
During years 1 and 2, Raphael Navarro, Sue Galvin, and I solved a number of technical problems associated with measuring the off-axis optical quality of the human eye. We are using a variation of the technique introduced by Campbell and Green for assessing optical quality at the fovea. Now that the new interferometer is completed, we can begin collecting final data on this project in September.

(10) Experiments on the Locus of an Early Nonlinearity in the Visual System
During year two, Chen Bing, Walt Makous, and I completed experiments showing that a nonlinearity in the visual system responsible for spatial harmonic distortion probably resides in the outer plexiform layer of the retina. We have shown that there is some low spatial frequency attenuation introduced prior to the nonlinearity, excluding cones as the locus for the nonlinearity. On the other hand, the spatial bandwidth of the stage prior to the nonlinearity is consistent with the size of individual cones even in retinal regions where there is considerable convergence of the cones onto bipolars cells. This makes the outer plexiform layer the most probable cite for the nonlinear phenomenon. A manuscript is in preparation.

PUBLICATIONS

Sekiguchi, N. and Williams, D.R. (1989) Analyses of the Living Human Cone Mosaic with Laser Interferometry. *Japanese Journal of Optics, 18,* 510-515.

Williams, D.R. (1990) Seeing in the light and in the dark. *Optics and Photonics News, 1, 36-37.*

Williams, D.R. (in press) The invisible cone mosaic. Proceedings from the National Research Council Symposium on Photoreception.

Williams, D.R. (in press) Photoreceptor sampling and aliasing in human vision. In: *Tutorials in Optics,* Optical Society of America.

Sekiguchi, N., Williams, D.R., and Packer, O. (in press) Nonlinear distortion of gratings at the foveal resolution limit. *Vision Res.*

Coletta, N.J., Williams, D.R., Tiana, C.L.M. (in press) Consequences of spatial sampling for human motion perception. *Vision Res.*

Tiana, C.L.M., Williams, D.R., Coletta, N.J., and Haake, P.W. (in press) A model of aliasing in extrafoveal human vision. In "Computational Models of Visual Processing." Eds. Landy, M. and Movshon, A. MIT Press.

Lennie, P., Haake, W., and Williams, D.R. (in press) The design of chromatically opponent receptive fields. In "Computational Models of Visual Processing." Eds. Landy, M. and Movshon, A. MIT Press.

Williams, D.R., Sekiguchi, N., Brainard, D., Haake, P., and Packer, O. (in preparation) Spatial aliasing by red-green chromatic mechanisms. To be submitted to *Nature*

Williams, D.R., Sekiguchi, N., Brainard, D., Haake, P., and Packer, O. (in preparation) Spatial interpolation and trichromatic spatial sampling in human vision. Chapter to appear in "Advances in Understanding Visual Processes: Convergence of Neurophysiological and Psychophysical Evidence" edited by A. Valberg and B.B. Lee, Plenum Press.

Packer, O., and Williams, D.R. (in preparation) Eye movements and visual resolution. To be submitted to *Vision Res.*

MacLeod, D.I.A, Williams, D.R., and Makous W. (in preparation) Difference frequency gratings above the resolution limit. To be submitted to *J. Opt. Soc. Am.*

Makous, W., Williams, D.R., MacLeod, D.I.A. (in preparation) A nonlinearity in early vision. To be submitted to *J. Opt. Soc. Am.*

Chen, B., Makous, W., and Williams, D.R. (in preparation) Locus of an early non-linearity in the visual system. To be submitted to *J. Opt. Soc. Am.*

PERSONNEL ENGAGED ON PROJECT

The following personnel have been actively involved in the projects described above:

David Brainard. Postdoctoral fellow supported by AFOSR and NRSA fellowship.

Bing Chen. Postdoctoral Fellow, supported in part by AFOSR.

Nancy Coletta. Former postdoc, now an assistant professor at the University of Houston.

Susan Galvin. Graduate student supported by University fellowship.

Bill Haake. Systems Analyst supported by AFOSR.

Kyunghee Koh. Postdoctoral fellow supported 50% by AFOSR.

Peter Lennie. Faculty Member.

Walter Makous. Faculty Member.

Rafael Navarro. Visiting scholar from Instituto des Opticas, Madrid, Spain.

Orin Packer. Postdoctoral fellow supported by NRSA Fellowship.

Al Russell. Electronics engineer.

Nobutoshi Sekiguchi. Graduate student supported by Olympus Optical Corporation.

Carlo Tiana. Graduate student supported by AFOSR.

LIST OF INTERACTIONS

Presentations at Professional Meetings:

Chen, B., Makous, W. and Williams, D.R. A nonlinearity localized in the outer plexiform layer. Association for Research in Vision and Ophthalmology, Sarasota, FL, 1989.

Packer, O., Williams, D.R., Sekiguchi, N., Coletta, N.J. and Galvin, S. Effect of chromatic adaptation on foveal acuity and aliasing. Association for Research in Vision and Ophthalmology, Sarasota, FL, 1989.

Lennie, P., Haake, P.W. and Williams, D.R. Chromatic opponency through random connections to cones. Association for Research in Vision and Ophthalmology, Sarasota, FL, 1989.

Lennie, P. Haake, P.W. and Williams, D.R. Chromatic opponency through indiscriminate connections to cones. Optical Society of America, Orlando, Fla., October, 1989.

Williams, D., Coletta, N., Tiana, C., Haake, W. Spatial sampling & image motion, Workshop on Computational Models of Visual Processing, Cold Spring Harbor, June 1989.

Williams, D.R. Photoreceptor sampling of moving images. Applied Vision Topical Meeting, San Francisco, CA, July 1989.

Williams, D.R., Coletta, N., Tiana, C. and Packer, O. Spatial sampling, image motion, and visual resolution. "Optics, Physiology and Vision," The Westheimer Symposium, San Francisco, CA, August 1989

Lennie, P. Haake, P.W. and Williams, D.R. Chromatic opponency through indiscriminate connections to cones. Optical Society of America, Orlando, Fla., October, 1989.

Packer, O. and Williams, D.R. Eye movements and visual resolution. Association for Research in Vision and Ophthalmology, Sarasota, FL, 1990.

Koh, K., Lennie, P., and Williams, D.R. Mechanisms of adaptation to chromatic fringes. Association for Research in Vision and Ophthalmology, Sarasota, FL, 1990.

Williams, D.R., Sekiguchi, N, and Packer O. Spatial aliasing by chromatic mechanisms. Association for Research in Vision and Ophthalmology, Sarasota, FL, 1990.

Sekiguchi, N., Packer, O. and Williams, D.R. Spatial sampling by chromatic

mechanisms in human vision. Society for Photographic Science and Engineering, Rochester, NY, 1990.

Packer, O. and Williams, D.R. Do eye movements affect visual resolution? Society for Photographic Science and Engineering, Rochester, NY, 1990.

Williams, D.R., Sekiguchi, N. and Packer, O. Spatial sampling by the human foveal cone mosaic and its implications for color vision. International Congress of Eye Research, Helsinki, Finland, 1990.

Williams, D.R. Interpolation and trichromatic spatial sampling in foveal vision. Advances in Understanding Visual Processes. Roros, Norway, 1990.

Colloquia:

Color vision and the cone mosaic, New York University, 1988.

Limits of spatial vision, University of Alabama, 1988.

A nonlinearity in early spatial vision, Columbia University, 1989

Aliasing in human foveal vision, Columbia University, 1989

Spatial sampling in human vision, University of Texas, Austin, 1989

Image motion and spatial sampling, University of California, San Diego, 1989

On measuring the cone mosaic in the living human eye. Eye Research Institute, Boston, MA, 1989

There is more to seeing than meets the eye. University Forum, University of Rochester, 1989.

Spatial sampling in human vision. University of Waterloo, Waterloo, Canada, 1990.

Spatial aliasing by chromatic mechanisms in human vision, Polaroid Corporation, Boston, MA, 1990.

Spatial aliasing by chromatic mechanisms in human vision, University of Michigan, Ann Arbor, MI, 1990.

Consulting:

Visited the Night Vision and Electro-Optics Laboratory, Fort Belvoir, MD. to discuss potential improvements in night vision goggles worn by Army helicopter pilots, 1990.

Inventions/Patents:

None